Part I: Antiproton Cooling at Tevatron

Part II: VLHC

Vladimir Shiltsev
Fermilab

Antiproton Source and Collider Complex

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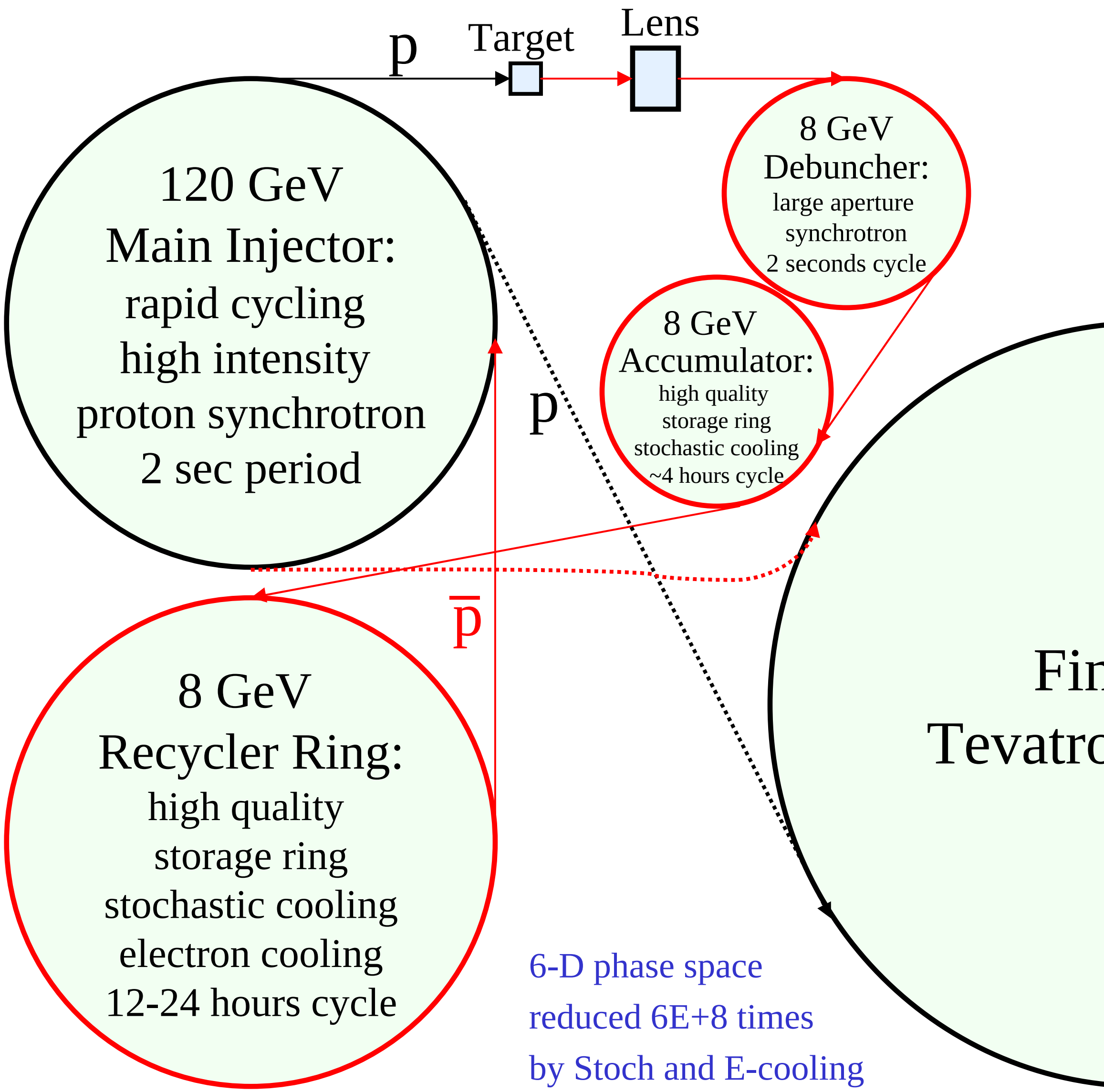

In operation:

Tevatron	1983
Pbar Source	1985
Main Injector	1999
Recycler	2004

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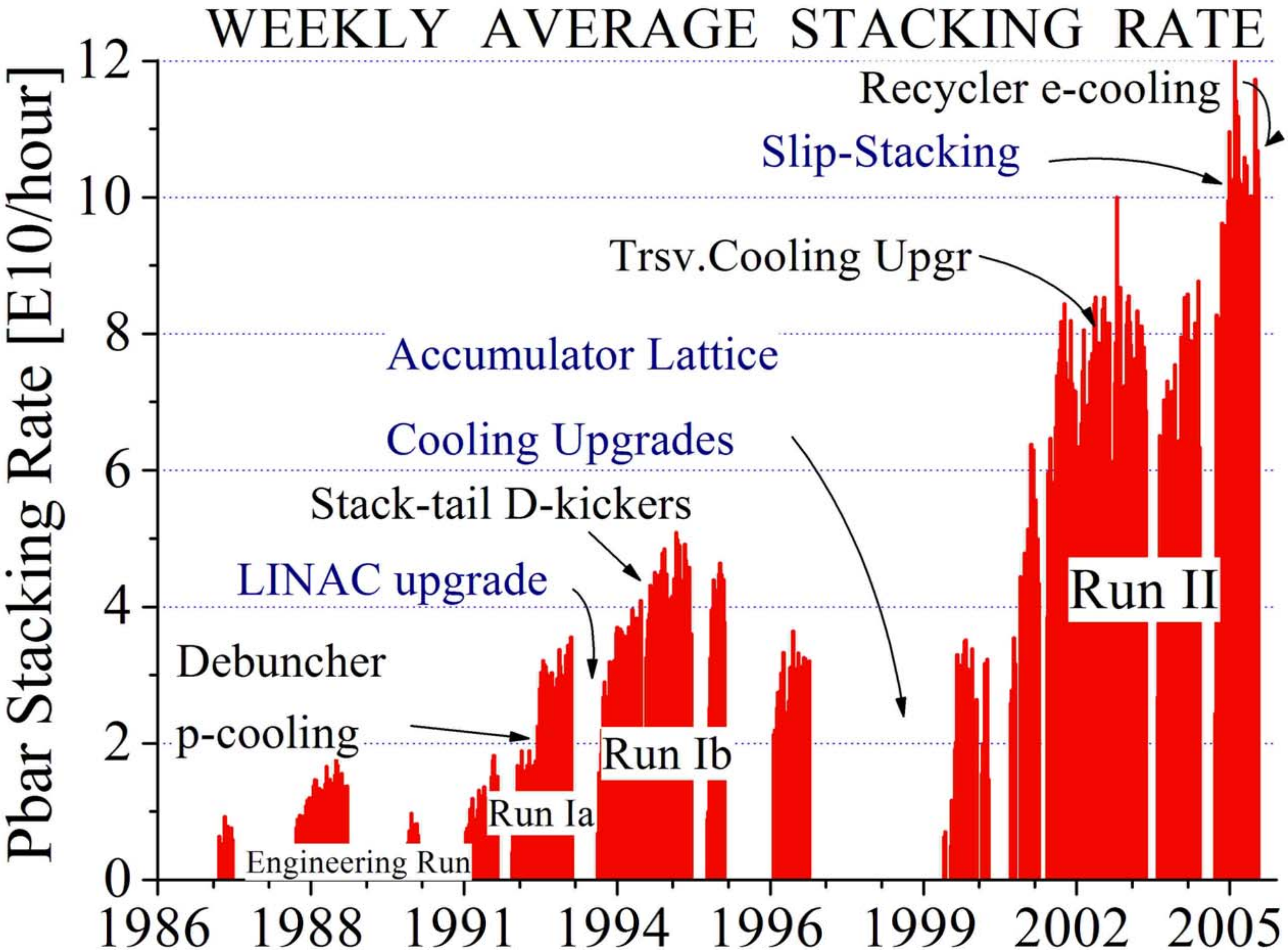
Antiproton Production at Fermilab



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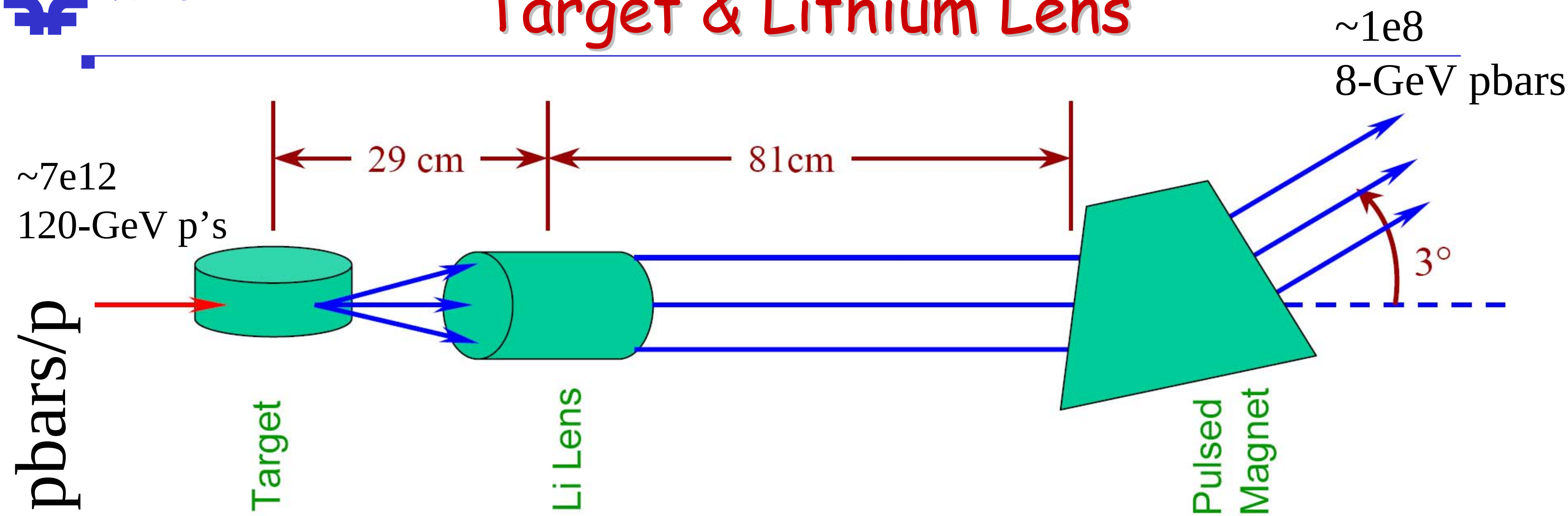
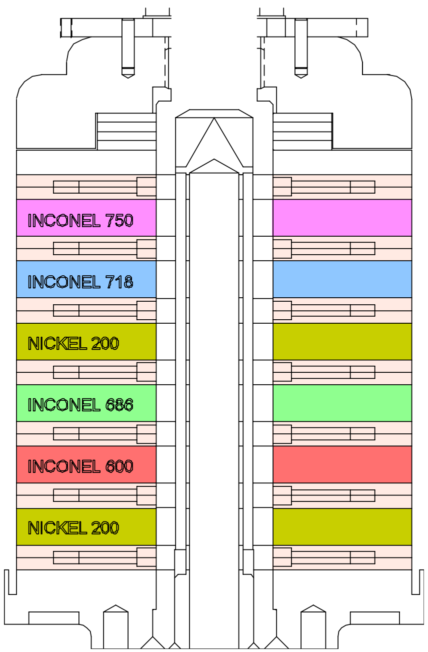
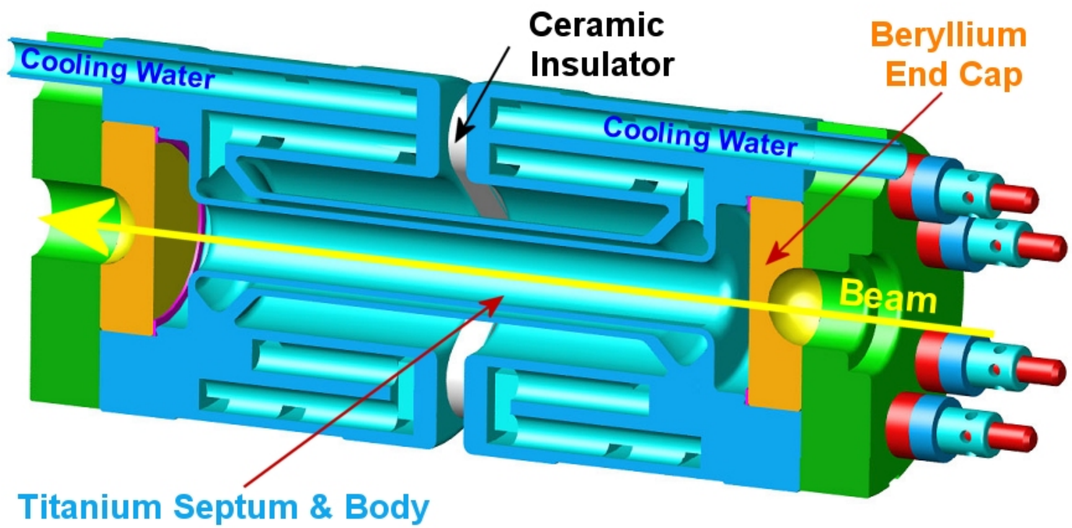
Target & Lithium Lens



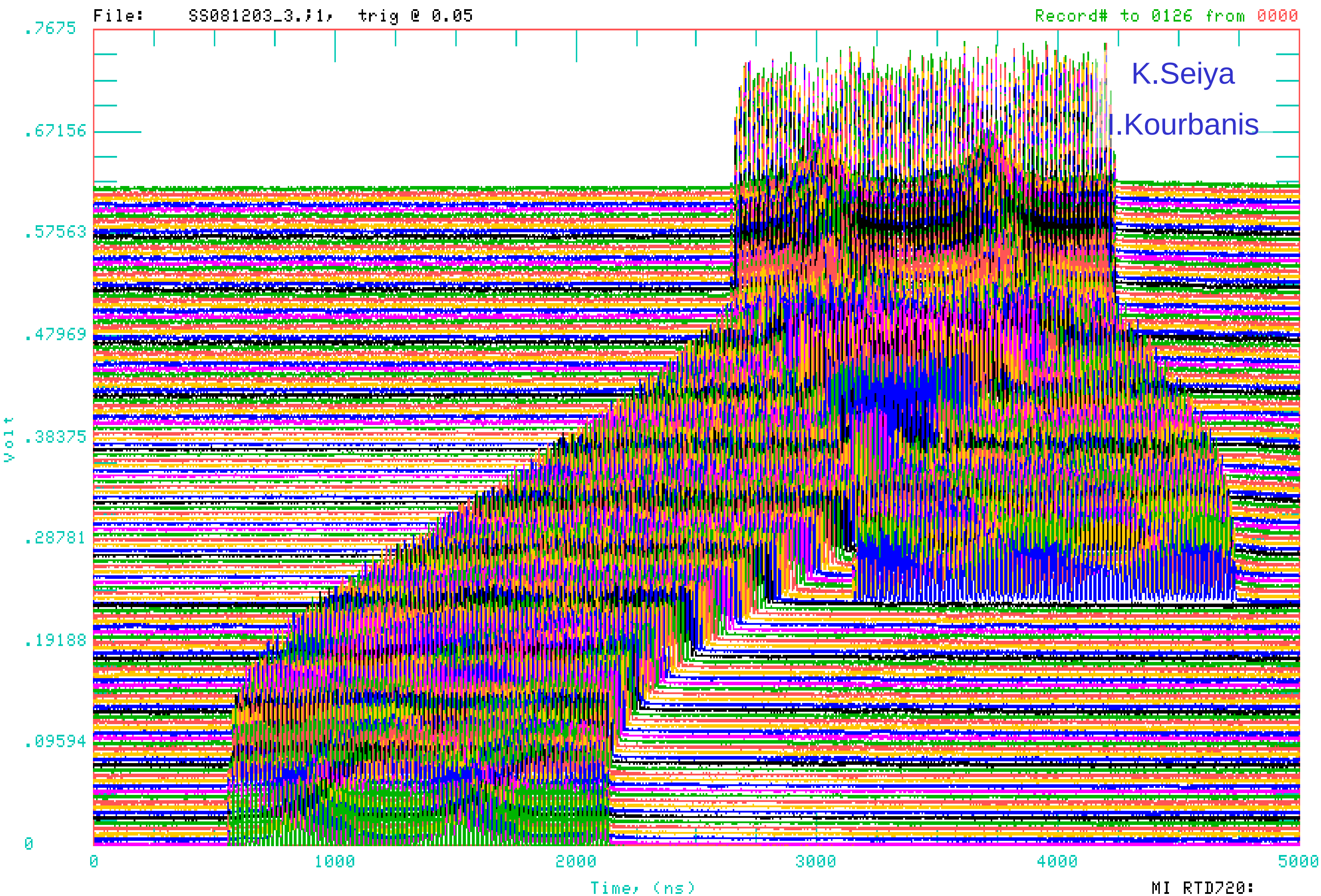
Yield ~1.8e-5 pbars/p





∅1cm; 10T/cm; 10M pulses (goal)

Slip Stacking (6-8)e12 p's in Main Injector



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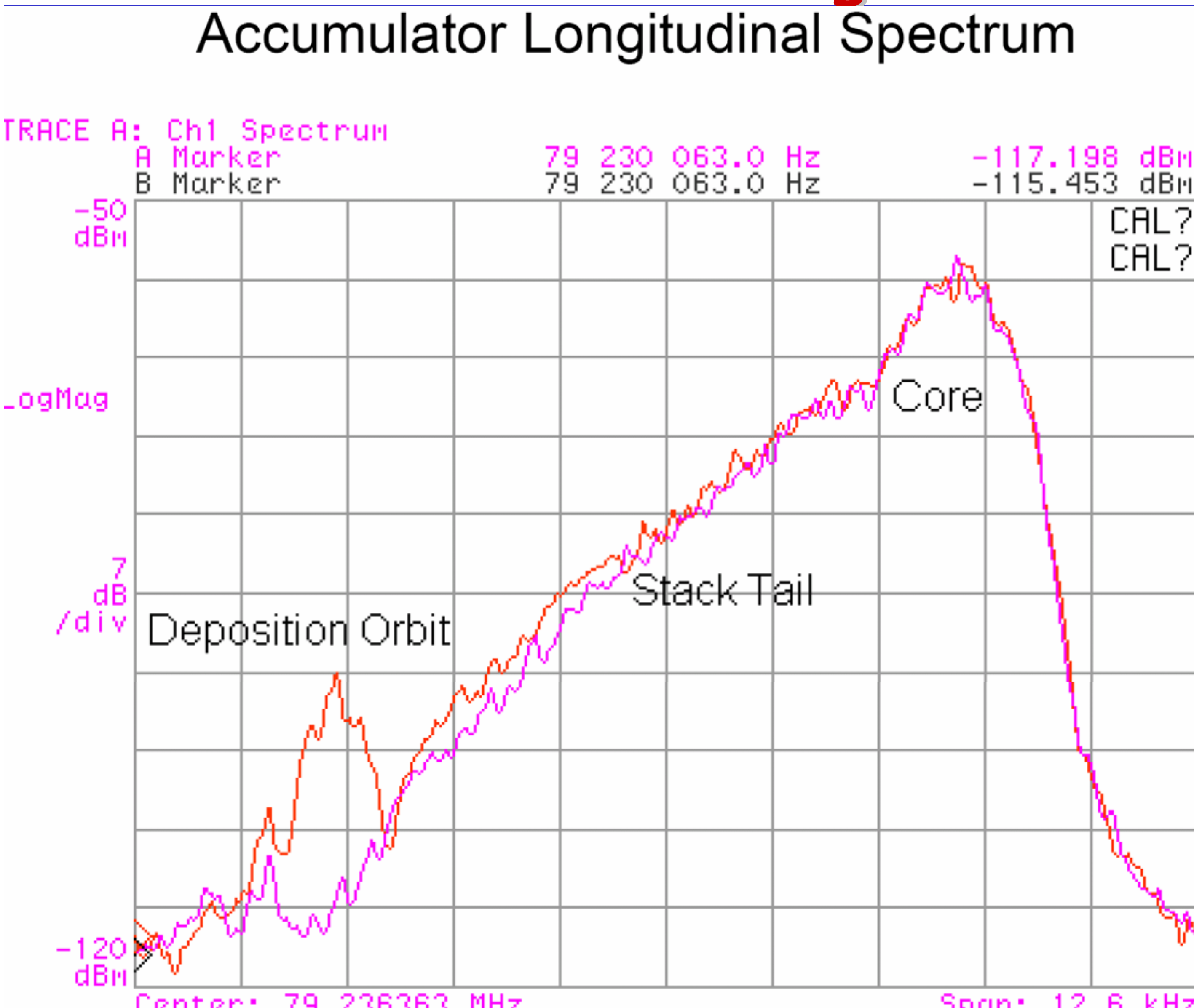
Stochastic Cooling in Accumulator



- We're switching to "Recycler only" shots to gain 10-15%

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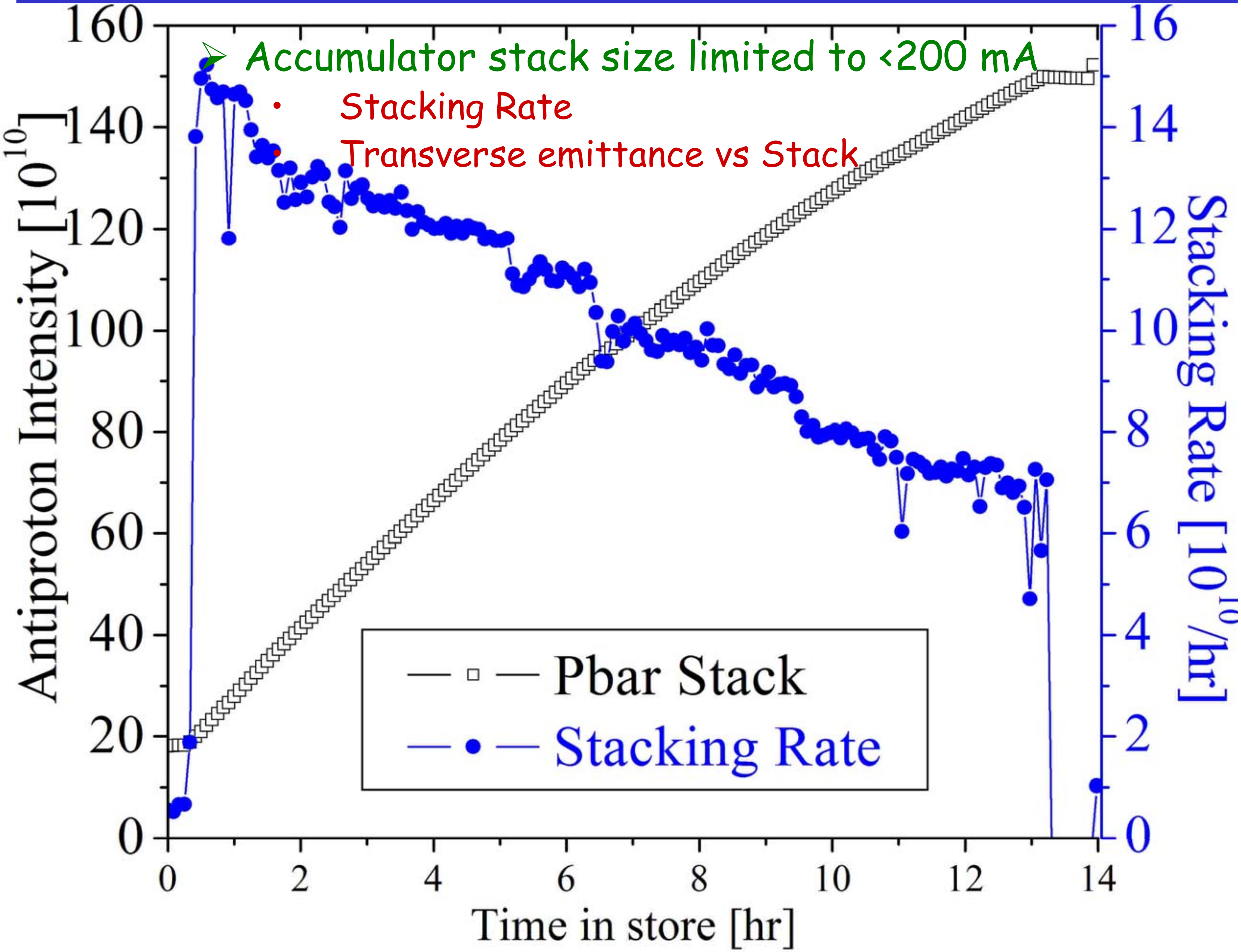
Antiproton Accumulator: Stacking Rate Falls

- Accumulator stack size limited to <200 mA
  - Stacking Rate
  - Transverse emittance vs Stack



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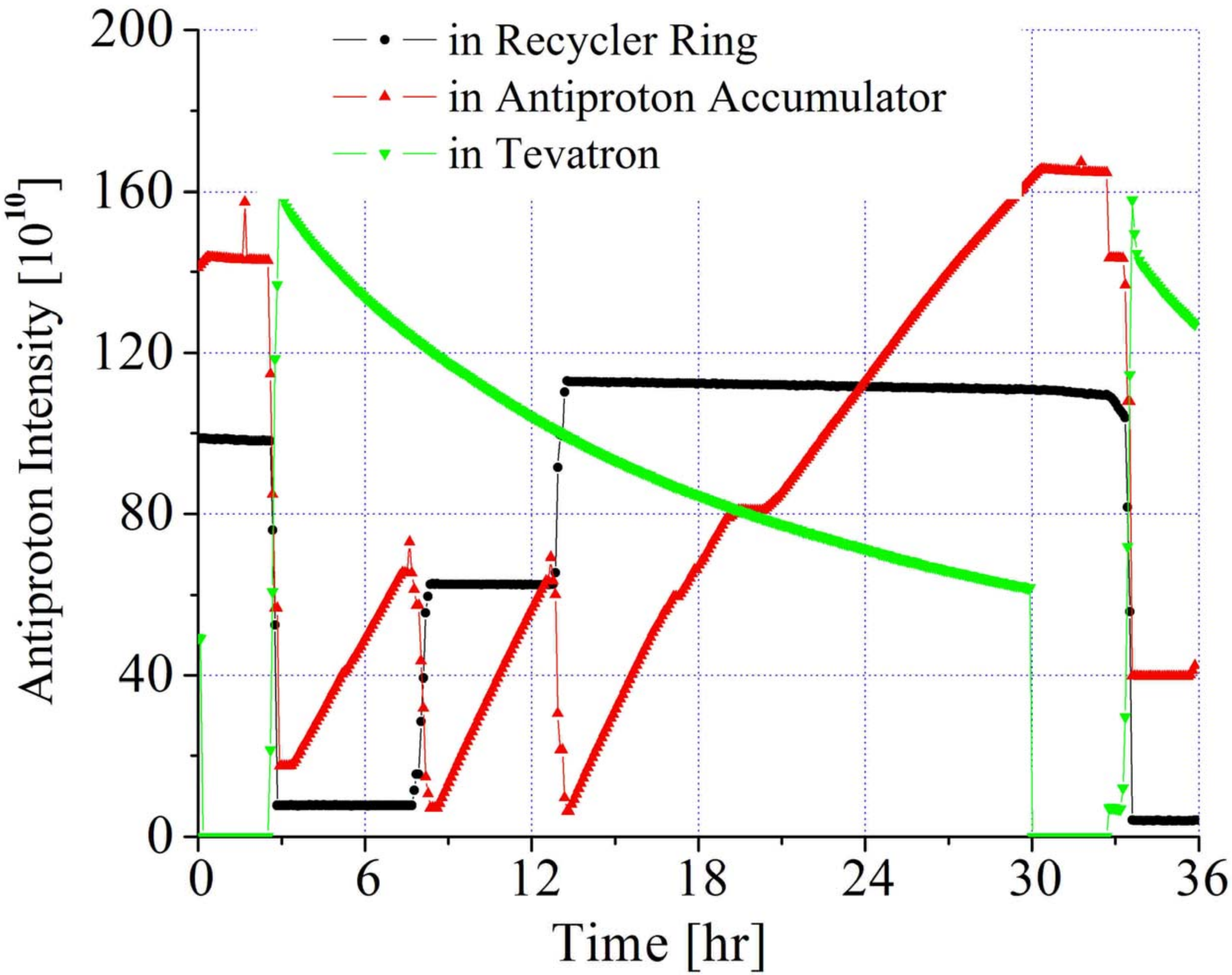
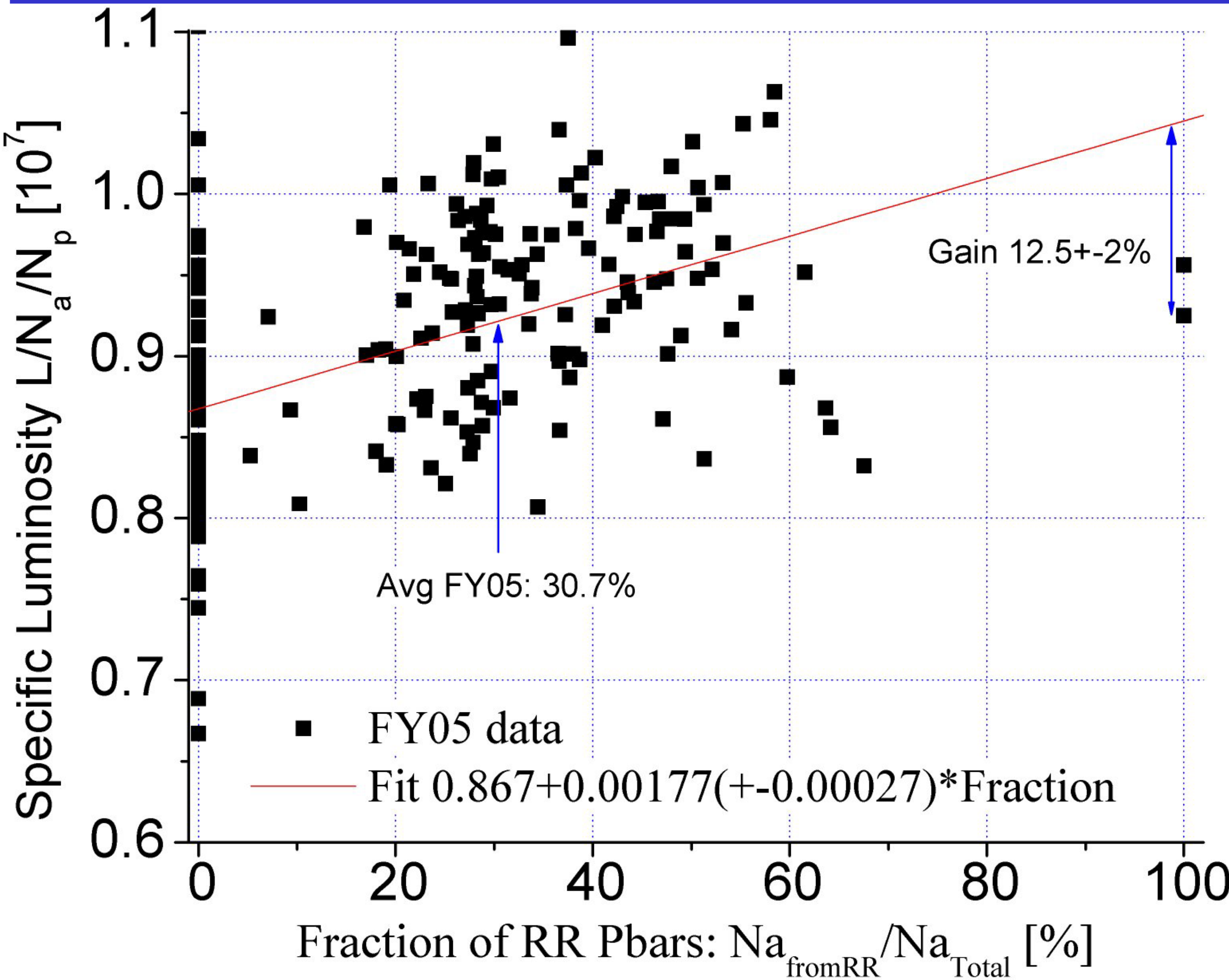
"Combined Source" Shots: (RR+AA) → Tevatron



Weaker IBS in Recycler → Smaller Emittance



- E-cooling allows "Recycler only" shots → gain 10-15%

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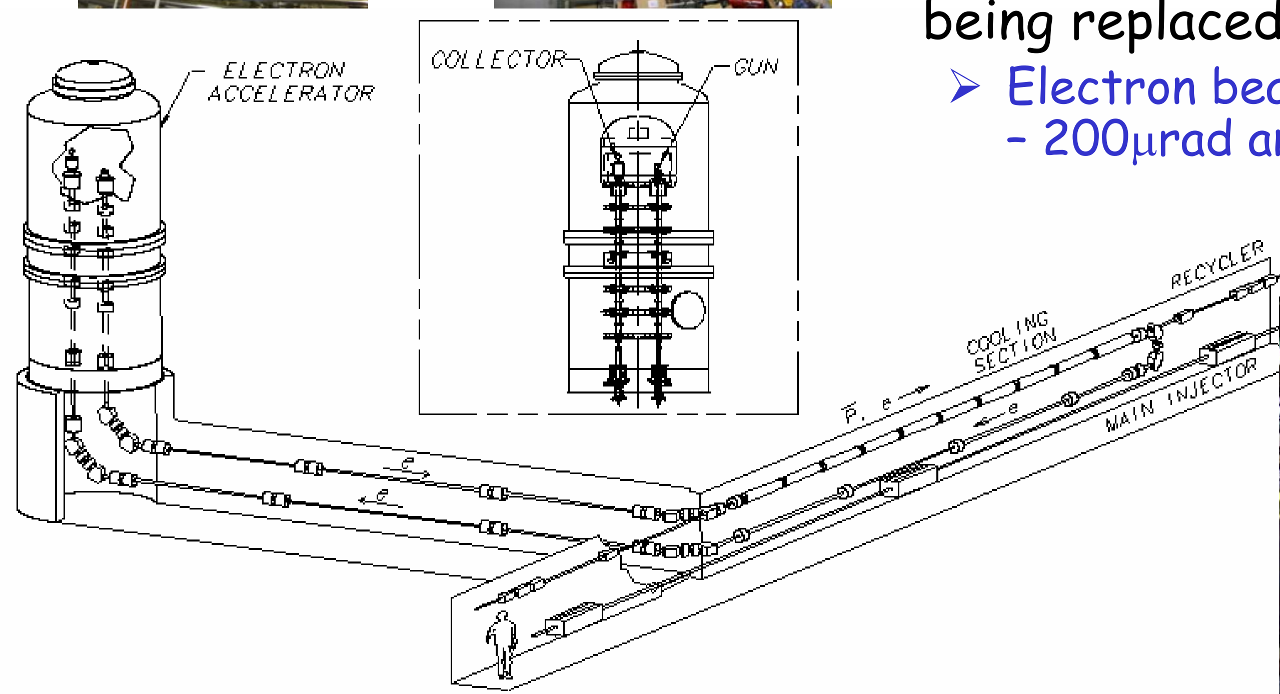
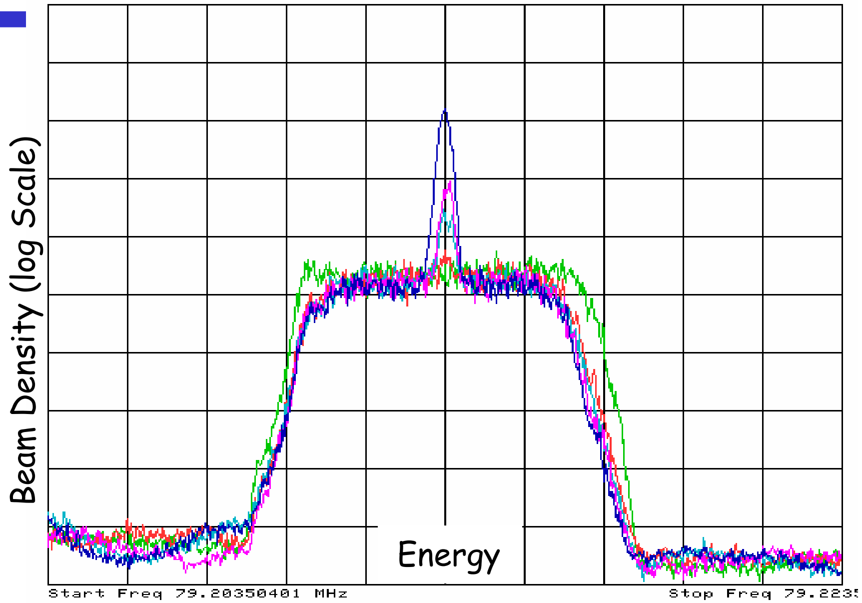
Recycler Electron Cooling

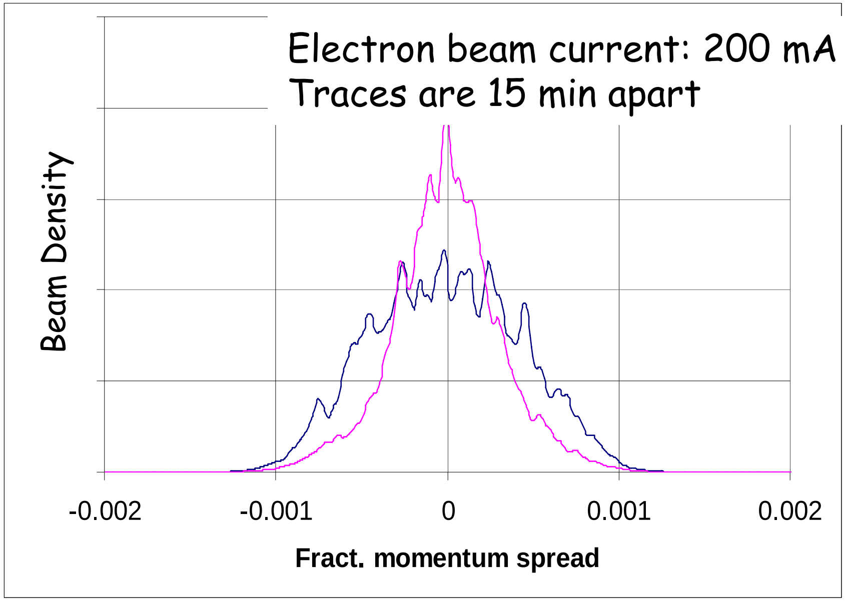
- The maximum antiproton stack size in the Recycler is limited by
  - Stacking Rate in the Debuncher-Accumulator at large stacks
  - Longitudinal cooling in the Recycler
- Longitudinal stochastic cooling of 8 GeV antiprotons in the Recycler is being replaced by Electron Cooling
  - Electron beam: 4.34 MeV – 0.5A DC – 200μrad angular spread



Electron Cooling Commissioning (July 05)

- Electron cooling commisioning
  - Electron cooling was demonstrated in July 2005 two months ahead of schedule.
  - By the end of August 2005, electron cooling was being used on every Tevatron shot
- Electron cooling rates
  - Drag rate: 20 MeV/hr for particles at 4 MeV
  - Cooling rate: 25 hr^{-1} for small amplitude particle
  - Can presently support final design goal of rapid transfers (30eV-sec every hour)
  - Have achieved 500 mA of electron beam which is the final design goal.





Electron Cooling in Operation

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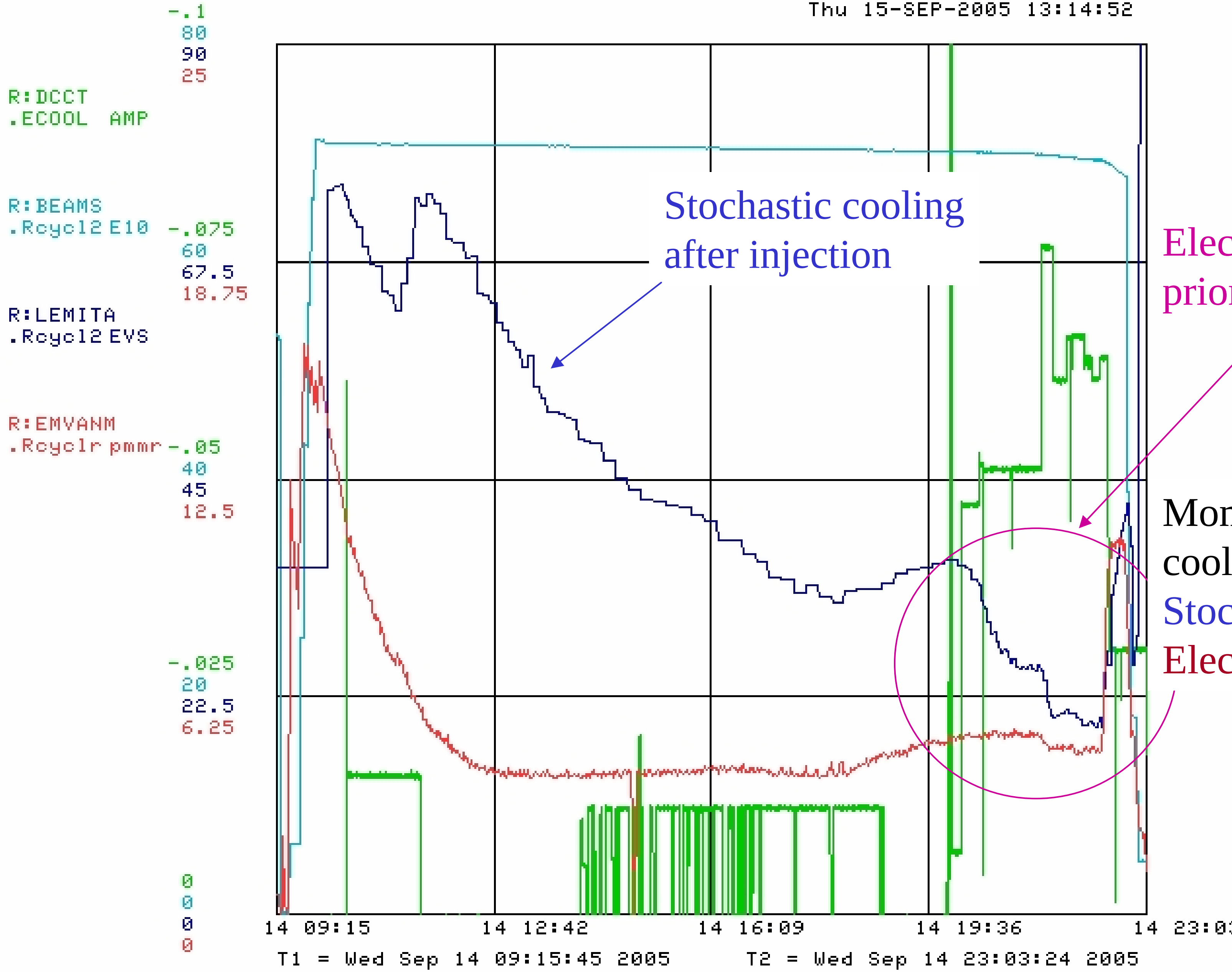

Momentum cooling times:

Stochastic ~3 hrs

Electron <1 hr

Very Large Hadron Collider

www.vlhc.org

FNAL-TM-2149
(2001)

Design Study for a Staged Very Large Hadron Collider

“Very Large” Part of VLHC

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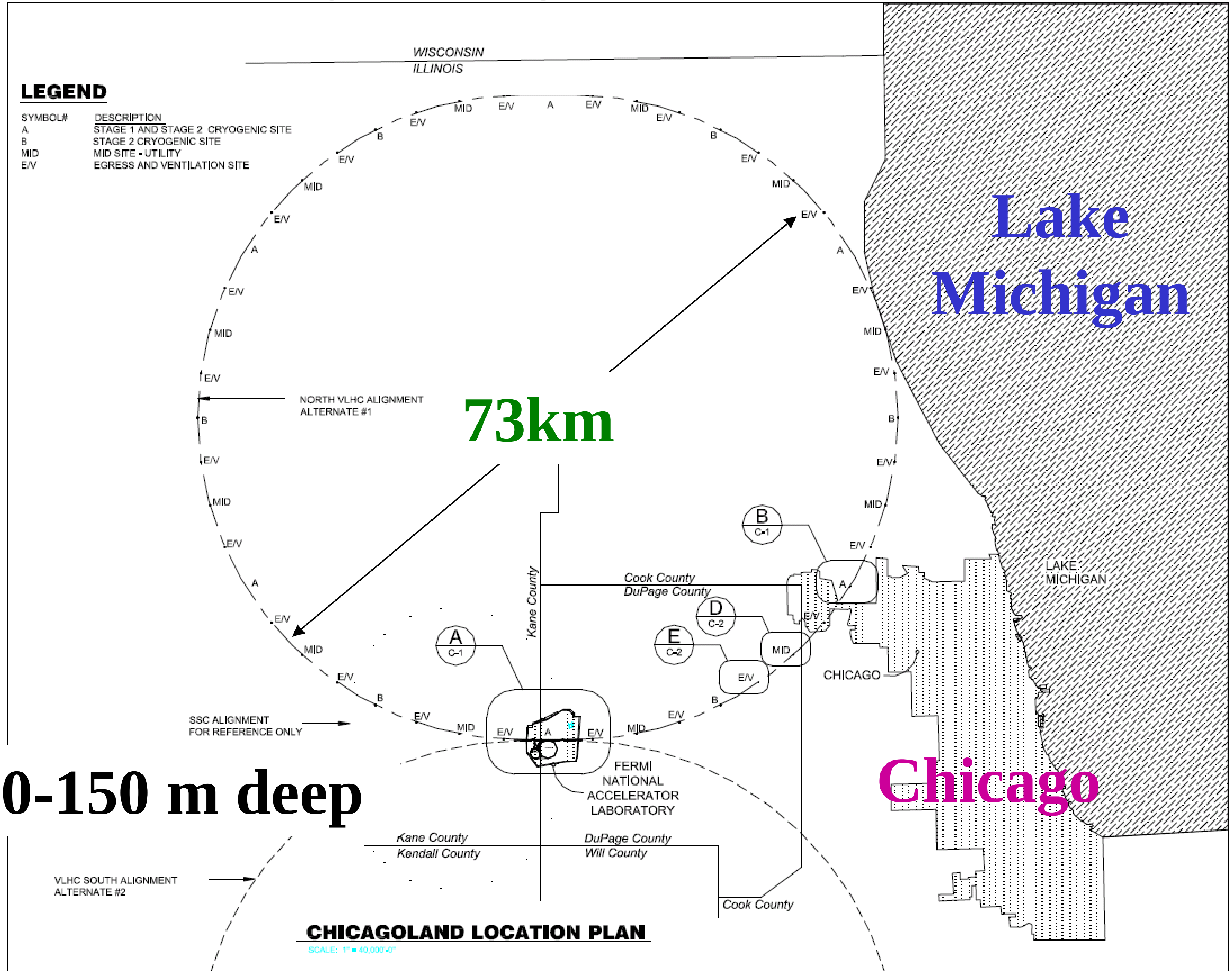

90-150 m deep

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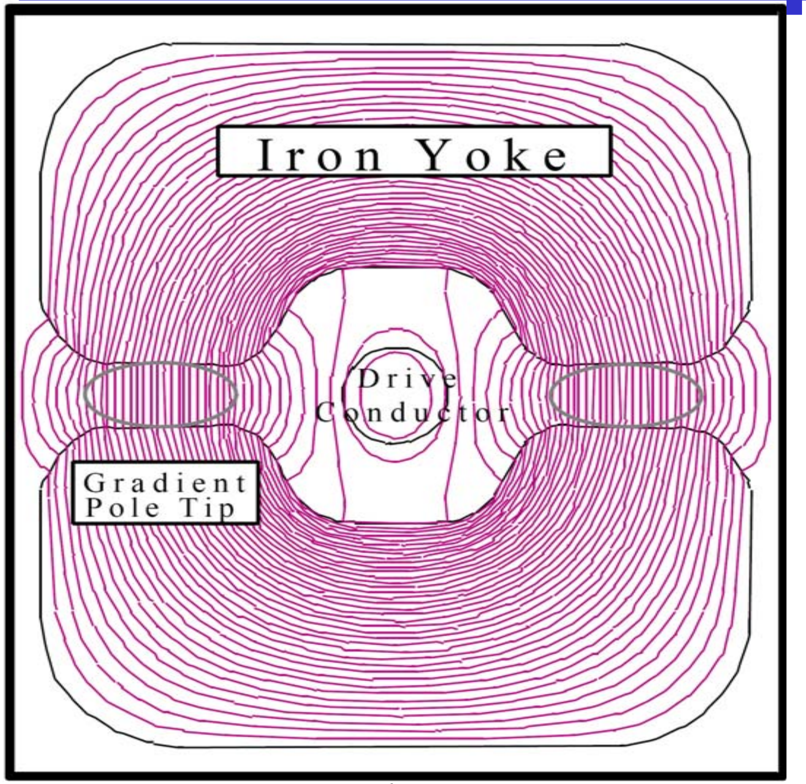
The Staged VLHC Concept

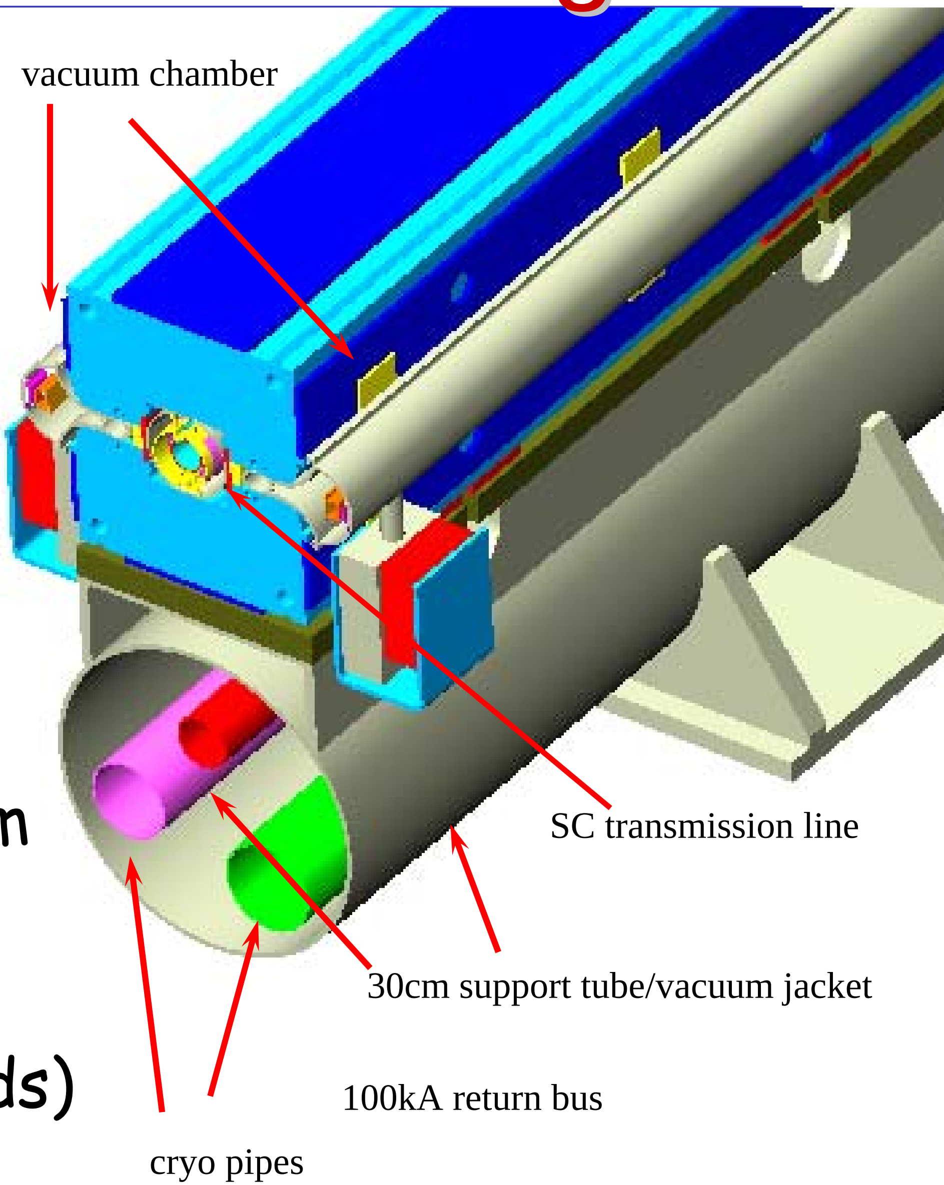
- Take advantage of the space and excellent geology near Fermilab.
  - **Build a BIG tunnel.**
  - **Fill it with a "cheap" 40 TeV collider.**
  - **Later, upgrade to a 200 TeV collider in the same tunnel.**
- There are no serious technical obstacles to the Stage-1 VLHC at 40 TeV and 10^{34} luminosity.
  - FNAL injector chain : MI + Tevatron
  - low operating cost (20 MW frige power, like Tevatron)
  - cost savings can be gained through underground construction
- Stage 2 VLHC is, technically, completely feasible
  - vigorous R&D will reduce magnet cost

VLHC Parameters

Fermilab-TM-2149 (2001)	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	200
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}
Dipole field at collision energy (T)	2	11.2
Average arc bend radius (km)	35.0	35.0
Initial Number of Protons per Bunch	2.6×10^{10}	5.4×10^{9}
Bunch Spacing (ns)	18.8	18.8
β^* at collision (m)	0.3	0.5
Free space in the interaction region (m)	± 20	± 30
Interactions per bunch crossing at L_{peak}	21	55
Debris power per IR (kW)	6	94
Synchrotron radiation power (W/m/beam)	0.03	5.7
Average power use (MW) for collider ring	25	100

Transmission Line Magnet

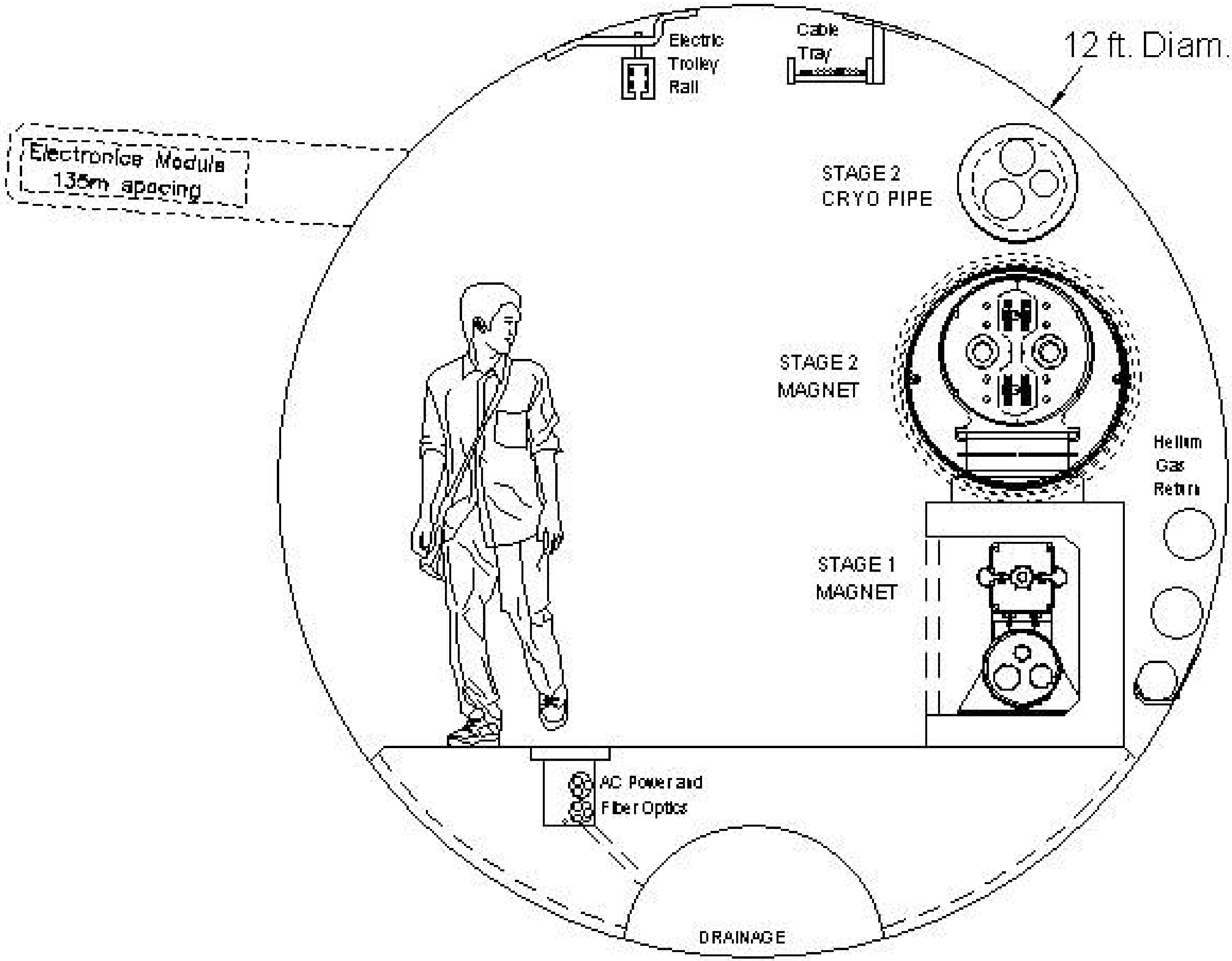




- warm iron and vacuum system
- superferric: 2T bend field
- 100kA Transmission Line
- alternating gradient (no quads)
- 65m Length

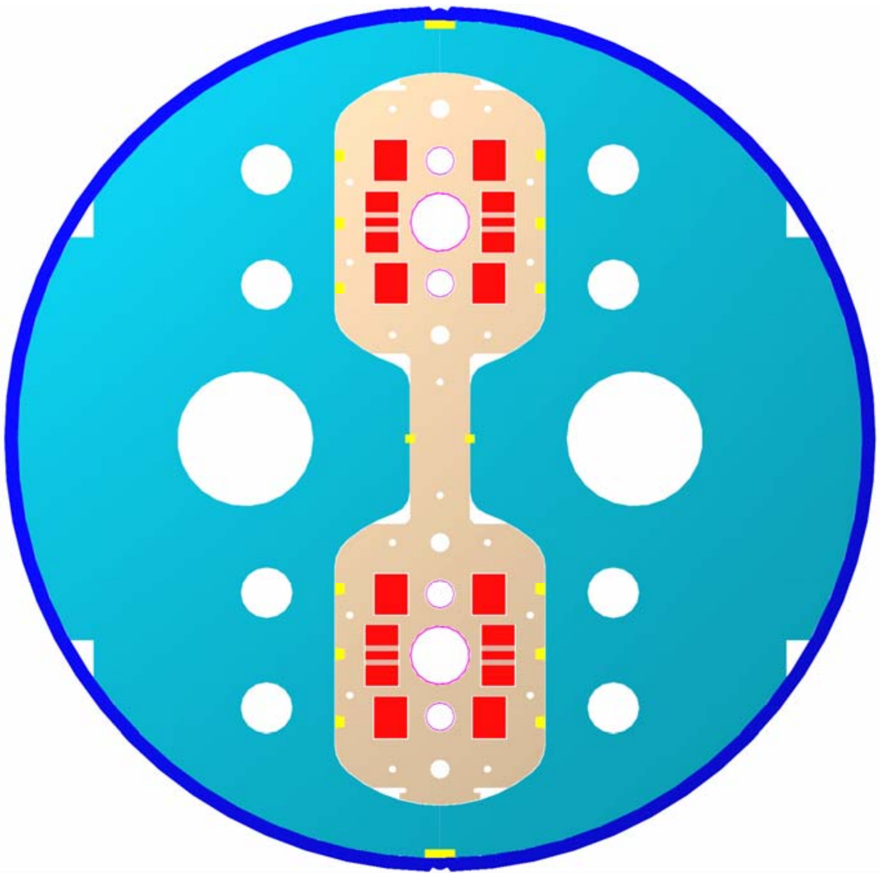
Stage-1 Magnet Yokes

VLHC Tunnel Cross Section

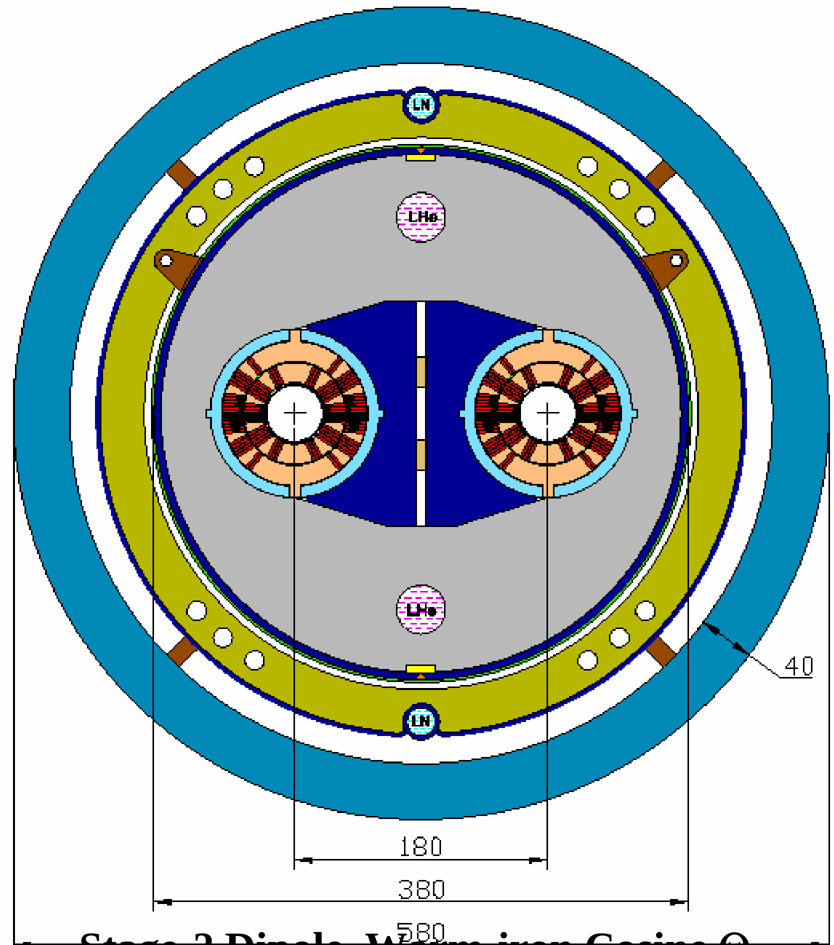


Stage-2 Magnets

- There are several magnet options for Stage 2. Presently Nb_3Sn is the most promising superconducting material.



Stage-2 Dipole Single-layer common coil



Stage-2 Dipole Warm-iron Cosine Θ

VLHC Cost Basis (2001)

- Used the “European” cost base
  - No detectors (2 halls included), no EDI, no indirects, no escalation, no contingency – a “European” base estimate.
- Estimated the cost drivers using a standard cost-estimating format. This is done at a fairly high level.
  - Underground construction (Estimates done by AE/CM firm)
  - Above-ground construction (Estimates done by FNAL Facility Engineering Section)
  - Arc magnets
  - Corrector and special magnets (injection, extraction, etc)
  - Refrigerators
  - Other cryogenics
  - Vacuum
  - Interaction regions
- Used today’s (2001) prices and today’s technology. No improvements in cost from R&D are assumed.

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VLHC Stage 1 Cost Drivers

In FY2001 K$	VLHC Estimate	VLHC Fraction
Total	**3,981,159**	**100.00%**
Civil Underground *	1,968,000	49.43%
Civil Above Ground	310,000	7.79%
Arc Magnets	791,767	19.89%
Correctors & Special Magnets	112,234	2.82%
Vacuum	153,623	3.86%
Installation	232,397	5.84%
Tunnel Cryogenics	22,343	0.56%
Refrigerators	94,785	2.38%
Interaction Regions	26,024	0.65%
Other Accelerator Systems	269,986	6.78%

* Underground construction cost is the average of the costs of three orientations, and includes the cost of a AE/CM firm at 17.5% of construction costs.

Comparison: the SSC Collider Ring, escalated to 2001 is $3.79 billion

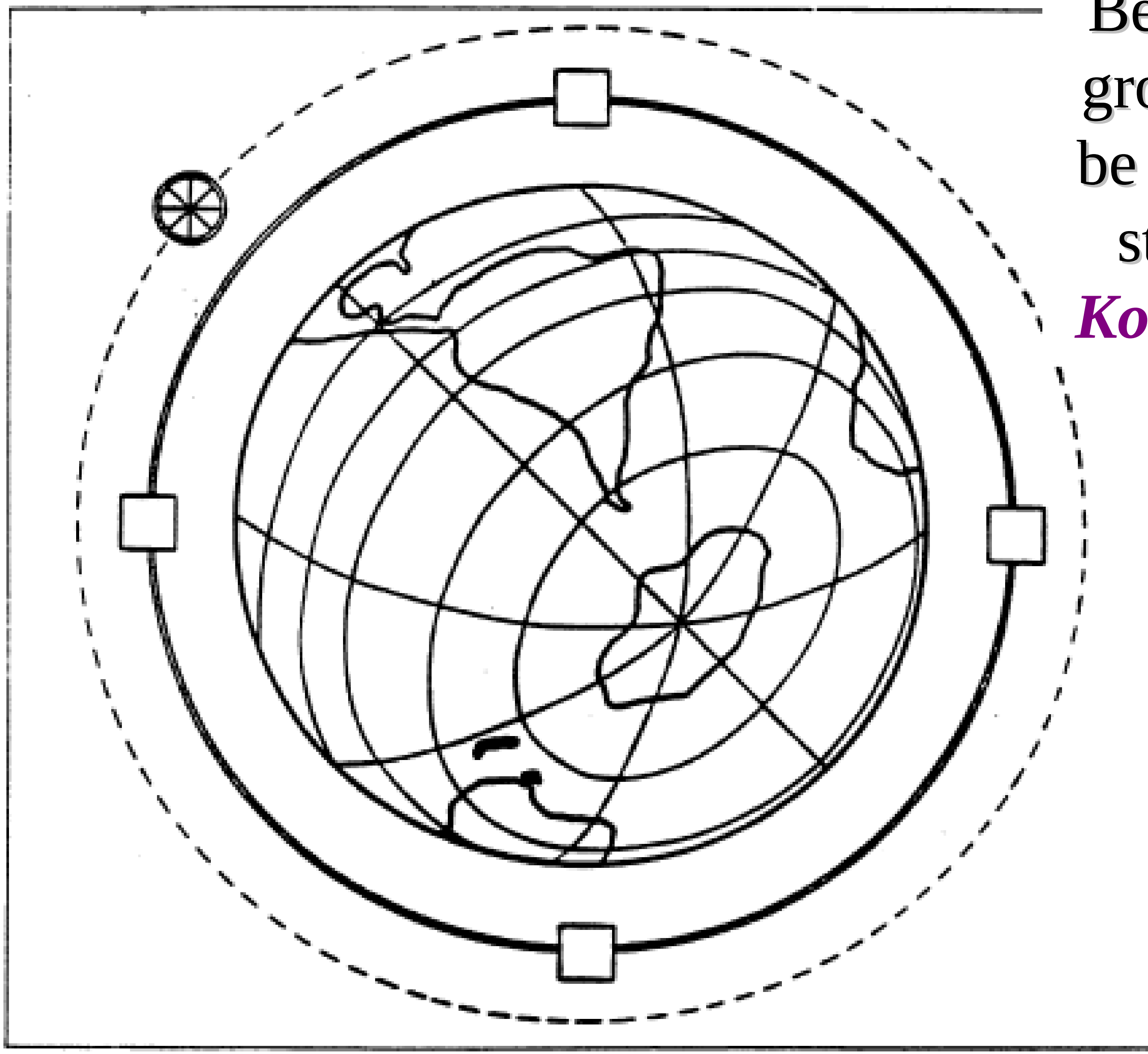
Ever Attractive Solution

- VLHC=Discovery Machine (just look back in hystory)
- The construction cost of the 1st stage of a VLHC is comparable to that of a linear e+e- collider, ~ $4 billion
- That is ~100M$/TeV vs 2-5B$/TeV for lepton colliders
- Based on three ~"loss-free" mechanisms:
  - Superconducting current flow
  - DC magnetization of iron
  - Recirculation of protons in guiding B-field
- VLHC is the only machine under discussion which does not throw away entire beam energy each pulse:
  - AC wall power VLHC-1 0.5MW/TeV vs 200+ MW/Tev for lepton colliders

Status and Outlook

- VLHC Study Report and Review (2001)
- Studies of Stage-1 and -2 magnets (2002-2003)
- Successful test of 100kA transmission line (2004)
- Excellent field quality in 2T magnets (2005)

- Expect to get input on:
  - High-Field Nb3Sn magnets ← from LHC Upgrade work
  - Cost of tunneling ← from ILC studies
  - Beam dynamics & vacuum ← from Tevatron, RHIC and LHC operation
  - Physics ← from theorists, Tevatron and LHC results



From a 1954 Slide by Enrico Fermi, University of Chicago Special Collections.

Be not afraid of growing slowly, be afraid only of standing still.

Korean Proverb